# GRAY WHALE FEEDING ECOLOGY

by

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## ABSTRACT

During three 1980 vessel cruises in the Northern Bering Sea, samples were taken to evaluate the feeding ecology of the gray whale. Side-scan sonar, close-circuit T.V. , remote bottom samplers and SCUBA divers were employed to describe and quantify the infaunal community consumed by whales.

The summer distribution of whales is constrained by the distribution of prey items. The largest aggregations of whales were found in the central Chirikov Basin over dense beds of amphipods. Densities of *Ampelisca macrocephala*, the dominant species, alone reached 22,450 individuals/$m^2$. The bottom sediments from this region are deeply pitted possibly as a result of foraging whales. Long-term experiments on the turnover rates of the benthic community were begun in the first of a proposed three year study.

# INTRODUCTION

## Gray Whale Feeding

Gray whales, like other large animals which feed on relatively small prey, are best described as omnivores. As befits a true omnivore, the list of gray whale food items is extensive, including both pelagic and benthic fauna. However at least since 1874, gray whales have been recognized as primarily bottom feeders earning the name "mussel-digger", with the reports of surfacing whales "besmeared with the dark ooze from the depths below" (Scammon 1874).

Stomachs from almost all gray whales taken in the breeding lagoons or while migrating have been empty or contained small amounts of seaweed, pebbles, and a few miscellaneous items such as polychaete tubes, ascidian tunics, and bivalve shells (Scammon 1874; Andrews 1914; Pike 1962; Rice and Wolman 1971). The few cases of full stomachs reported taken from migrating and wintering whales include pelagic prey items of sardines (Walker 1949), crab zoea larvae (Rice and Wolman 1971) and smelt (K. Balcomb as reported in Ray and Schevill 1974). Records of whales apparently feeding on baitfish (Sund 1975), the euphasiid *Euphausia pacifica* (Howell and Huey, 1930), and mys ids in kelpbeds (Wellington and Anderson 1978) augment the list of possible prey items. Although the gray whale may not feed extensively during the winter, it probably consumes a variety of pelagic, swarming foods opportunistically on its southern range.

There is little doubt however, that most of the whale's energy stores are accumulated on the northern feeding grounds. Although only indirect evidence exists to suggest gray whales feed during their northward migration while in Alaska (Braham in prep.), stomach contents of gray whales from the northern Bering and Chukchi Seas are almost entirely comprised of benthic amphipods (genera: *Ampelisca, Lembos, Anonyx, Pontoporeia, Hippomedon, Paraphoxus, Pleuster, Atylus, Protomedia, Acanthostepheia, Ischyrocerus,* and *Dulichia)* with assorted other bottom living organisms (Zenkovich 1934; Tomilin 1957; Pike 1962; Zimushko and Lenskaya 1970; Rice and Wolman 1971; Zimushko and Ivashin 1979; Bogoslovskaya et. al. 1980.) Few gray whales harvested in the summer have empty stomachs (Votrogov and Bogoslovskaya 1979). This suggests that they are continuously feeding or that they concentrate in areas of abundant food or both.

## Gray Whale Distribution

Sightings of gray whales in the northern Bering and Chukchi Seas from aerial and vessel platforms are plotted by month in Figures 1-6. The areas where whales aggregate correspond to regions where high density benthic amphipod communities are located. Data from Stoker (1978), Makarov (1937), and our 1980 cruises have been combined to produce Figure 7, a composite chart delineating the dense amphipod communities in the Bering Sea.

Sightings of gray whales well inside Norton Sound are uncommon, although some enter the Sound on an annual basis. Probably because of the finer sediment in Norton Sound, there is not a dense amphipod community as is found in the Chirikov basin (Stoker 1978).

Stomach contents of whales taken by Soviet whalers appear to reflect the composition of the benthic community where the whales were taken. Animals taken in the nearshore areas were found to be smaller in size and had been feeding

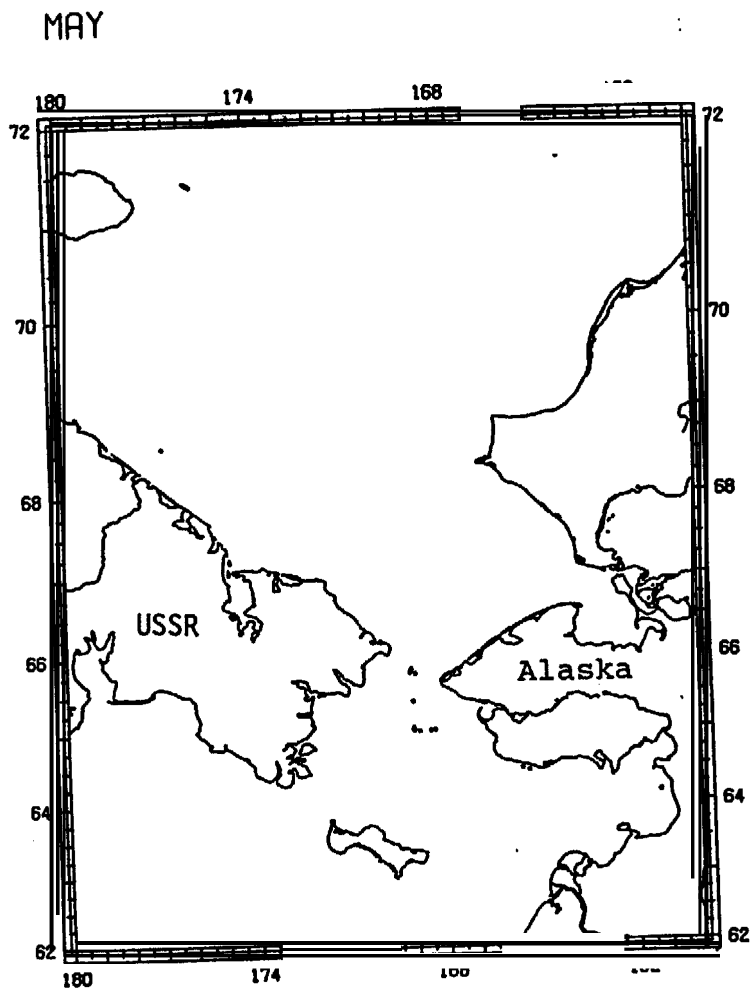


Figure 1. Gray whale distribution during May from N.M.F.S. aerial and vessel sightings 1975-1980 and B.L.M.-Project whales 1980 aerial data.

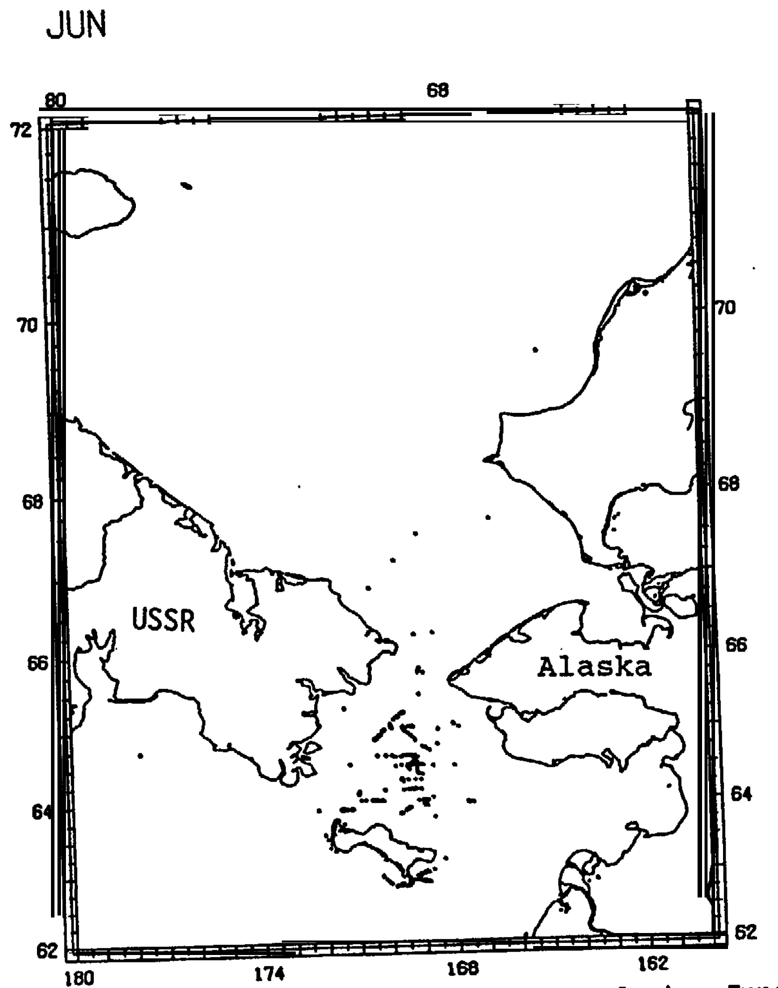


Figure 2. Gray whale distribution during June from N.M.F.S. aerial and vessel sightings 1975-1980.

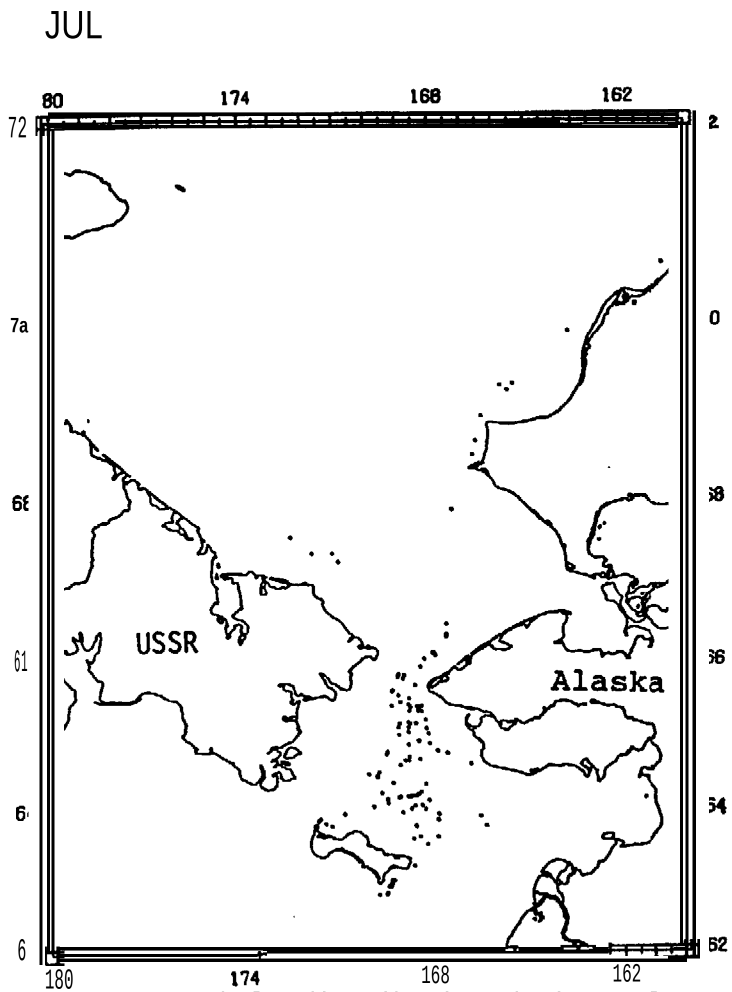


Figure 3. Gray whale distribution during July from **N.M.F.S.** aerial and vessel sightings 1975-1980.

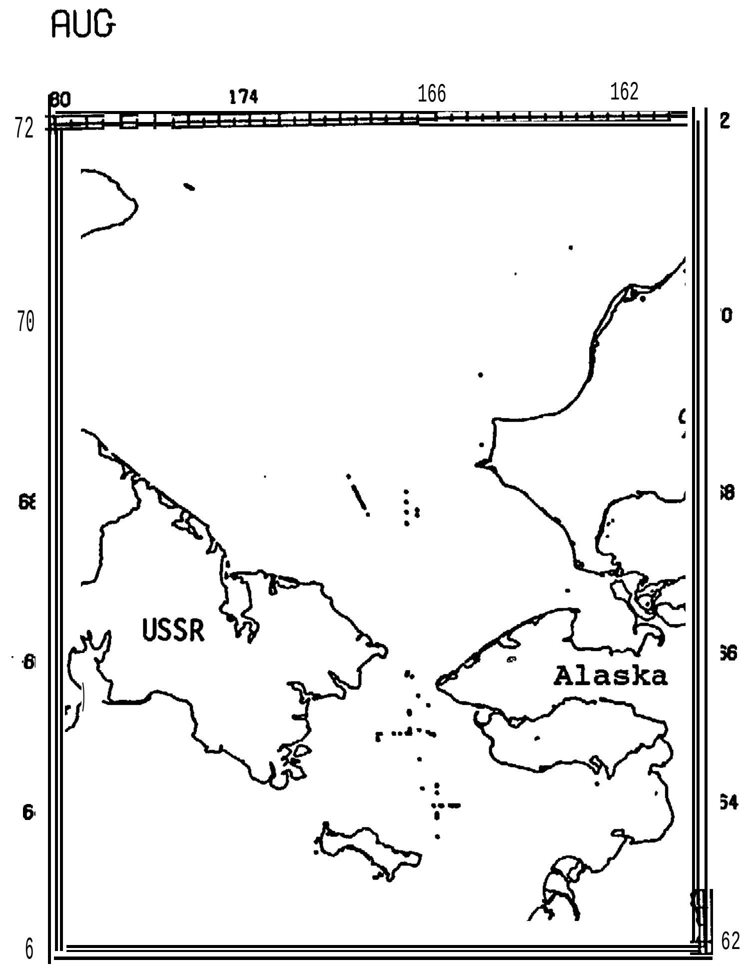


Figure 4. Gray whale distribution during August from **N.M.F.S.** aerial and vessel sightings 1975-1980.

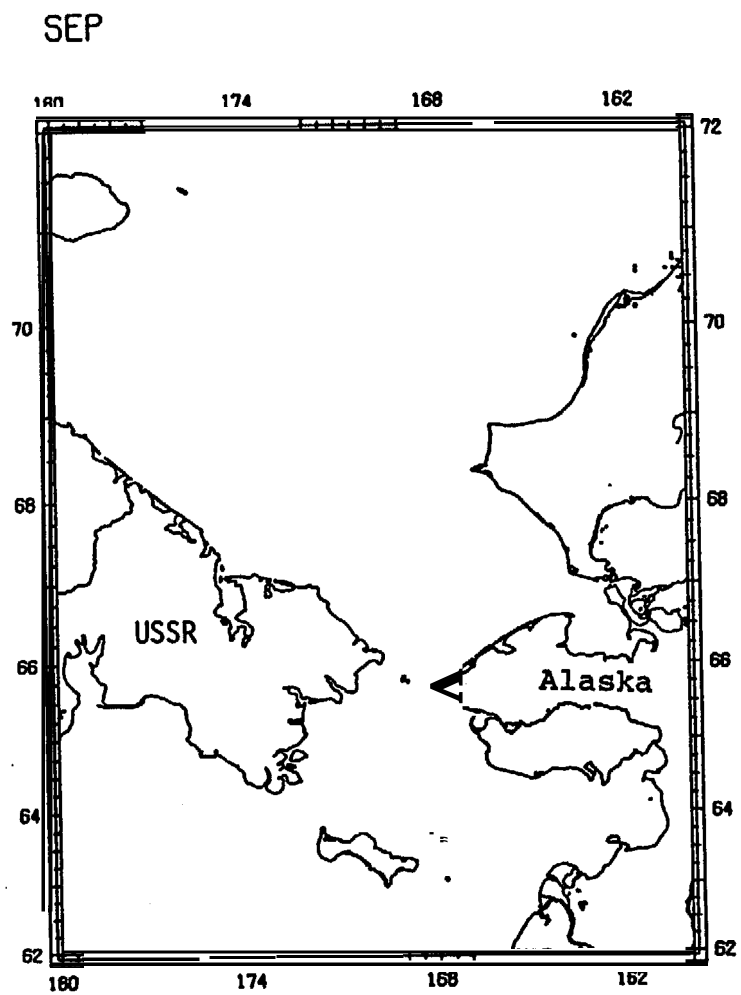


Figure 5. Gray whale distribution during September from N.M.F.S. aerial and vessel sightings 1975-1980.

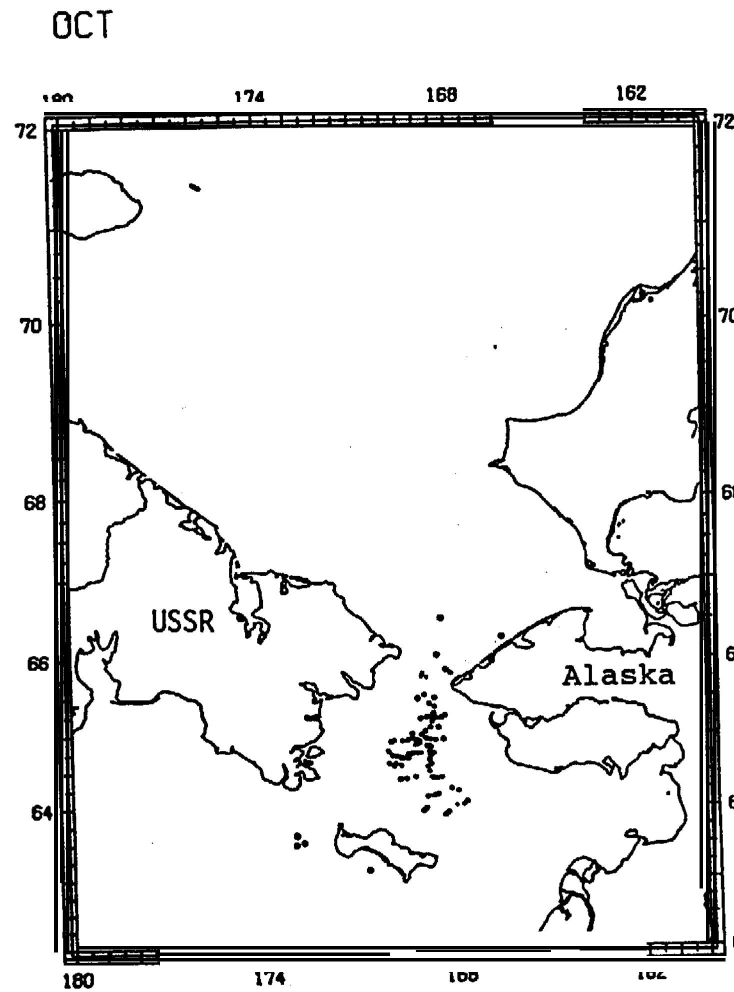


Figure 6. Gray whale distribution during October from N.M.F.S. aerial and vessel sightings 1975-1980 and B.L.M.-Project whales 1980 aerial data.

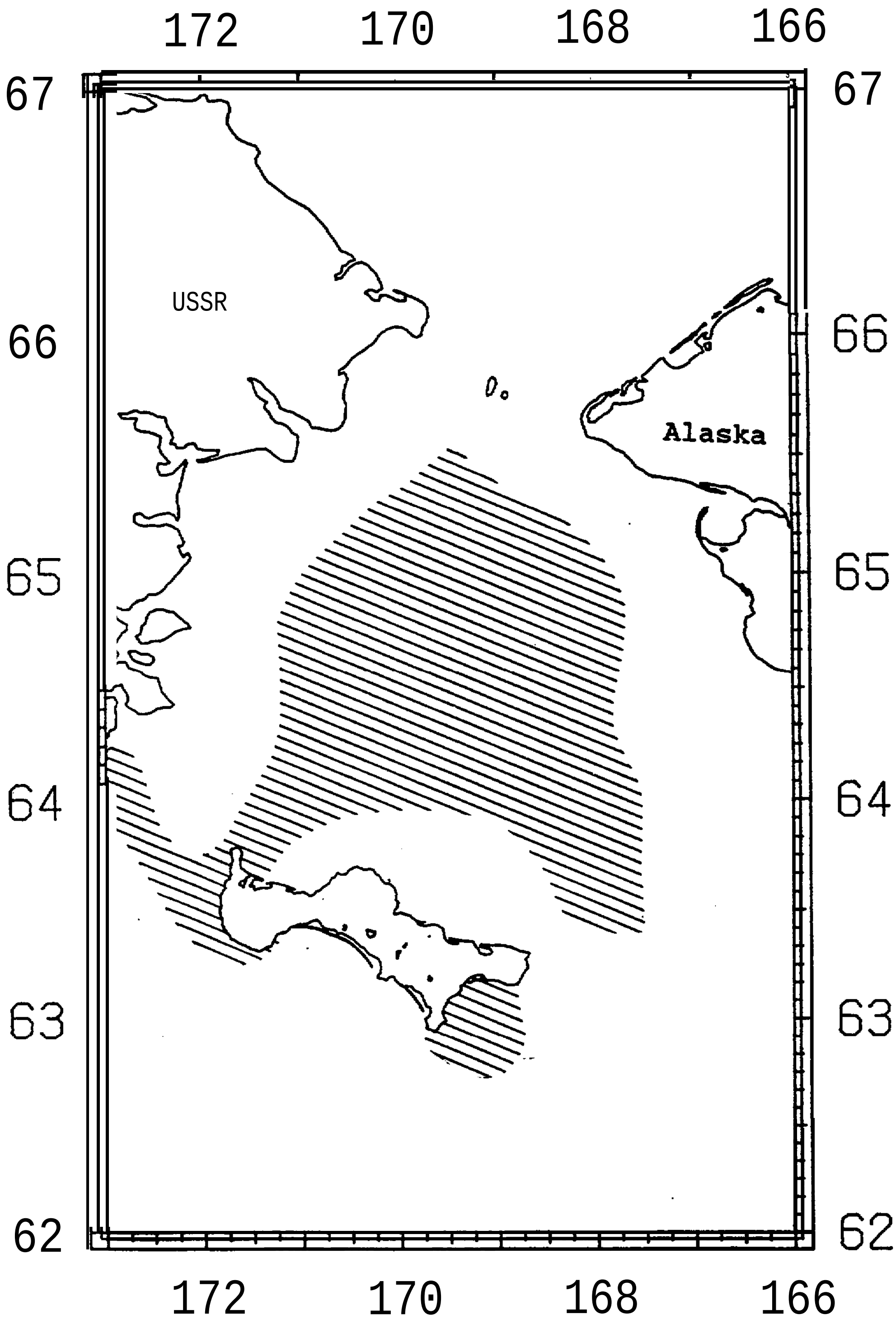


Figure 7. Schematic distribution of the dense benthic amphipod community in the northern Bering Sea.

mainly on the amphipod, Pontoporeia, in contrast to the large whales found further offshore which seem to exploit the vast Ampelisa amphipod concentrations (Zimushio and Ivashin 1979). It is noteworthy that the abundance of whales along "the Soviet coast was annually more variable than the abundance in the north central Bering Sea. Areas where whales were found in dense aggregations for several consecutive years were often found to be barren of whales in subsequent years (Votrogov and Bogoslovskaya 1979). This change in summer distribution may reflect a cyclical food resource. Comparing the Soviet whaling data (Zimushko and Ivashin 1979, Votrogov and Bogoslovskaya 1979) with the benthic communities in the northwestern Bering Sea (Makarov, 1937; Belyayev, 1960) one might infer that gray whales predictably return to the regions of dense Ampelisca beds. Clearly, gray whale distribution in the Bering Sea, and probably in the Chukchi Sea, is inexorably linked to amphipod concentrations.

## Objectives and Rationale

Information on the temporal and spatial patchiness of their food resource is integral to the understanding of gray whale feeding patterns. Thus, we have spent considerable effort to elucidate aspects of the benthic community dynamics in regions where gray whales feed. However, we approached the problem of cetacean feeding ecology[1] from several other aspects. Distributional data on summering whales was amalgamated from previous NMFS research (Wilke and Fiscus 1961; Braham et. al. 1977; Marquette and Braham 1980) and from 1980 BLM-Project Whales research to delineate areas that were frequently used by whales. Stomach contents of harvested whales were compared to the benthic community composition in the area where the whale was taken to validate the mechanism by which whales feed. We gathered data on gray whale dive times to determine activity budgets in foraging patterns. A side-scan sonar and an underwater video camera system were employed to evaluate the size and shape of whale-made disturbances as well as to evaluate how extensively a region of the ocean floor was used by whales. Infaunal data were. collected to allow us to compare the communities consumed by whales and concommitently, to create a hierarchy of important feeding localities to the stock of whales.

The objectives of our study were:

1. Detailed observations of feeding behavior of gray whales in areas where whales concentrate such as St. Lawrence Island.
2. Determination of benthic community structure before, during and after feeding groups have entered a feeding area.
3. Quantitative and qualitative analysis of stomach contents of landed gray whales taken by Soviet whalers in cooperation with Soviet scientists.
Analysis of additional stomach samples from gray whales landed by St. Lawrence Island Eskimos.
4. Gross quantification of the benthic consumption by the gray whale population in the area north of St. Lawrence Island and, on this basis, evaluation of the importance of this community to the stock of whales.

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[1] We note here that our research effort, designed to quantify and describe the relationship between a feeding whale and changes in its prey, is the first of its kind and thus is exploring untested theoretical and applied ecological questions.

5. Analysis of existing data on benthic community structure known to exist for areas near St. Lawrence Island.

## METHODS AND MATERIALS

### The Study Area

The areawe defined as our study area is the Chirikov Basin, between St. Lawrence Island and the Bering Strait, and between the Straits of Anadyr and outer Norton Sound. The whales are also found in the southern Chukchi Sea which, because it has greater estimated oil and gas resources (Bureau of Land Management, undated), would be a suitable area to study the impacts of development on the community in question, However, there is far more background data on the Chirikov communities, the area is shallower (which provided us with the possibility of using SCUBA divers), and the logistics appeared more manageable. For these reasons we chose to study the benthic system in the northern Bering Sea. Elucidation of of community dynamics in the Chirikov Basin will be pertinent to the understanding of gray whale-benthic interactions in other areas as well.

All field research was conducted in the northern Bering Sea from the NOAA ship Surveyor during 3 lags of cruise RP-4-SU80A, the dates of which were:

Leg I May 28-June 20, 1980 (Fig. 8)
Leg IX June 23-July 17, 1980 (Fig. 9)
Leg V Sept 10-Sept 30, 1980 (Fig. 10)

Because of extensive travel time to the study site from Kodiak, the nearest port where the Surveyor could refuel, we spent only 34 of the 67 cruise days actually in the northern Bering Sea. We employed the video camera system and remote benthic samplers on all Legs, as well as recording all marine mammal sightings as part of the NMML's Platforms of Opportunity Program. A leased helicopter was aboard during Leg II and diving operations occurred during Legs II and V. Side-scan sonar records were collected during Legs I and II.

### Vessel and Helicopter Operations

A Bell 206 helicopter was aboard the Surveyor from 13 June to 17 July, 1980. For navigation, it was equipped solely with a compass and radio direction finder. Aerial surveys were conducted with 2-3 observers and a recorder. We used systematic search patterns to locate whales, breaking the pattern only to circle over feeding whales when they were encountered. Transects and observations could only be made at altitudes greater than 500 feet. Lower altitudes disrupted feeding and caused the whales to submerge. During the 12 days the Surveyor was in the study area with the helicopter aboard, thirteen flights were initiated to gather data on location, distribution and behavior (primarily dive profiles) of gray whales. six of these flights were aborted due to fog and cloud cover. Of the remaining seven, five were used to gather data on location and relative distribution of animals while the other two flights were used to gather data on feeding behavior.

### Behavior Observations

The helicopter was helpful in finding different aggregations of gray whales and in determining the number of animals in the group. Behavioral observations

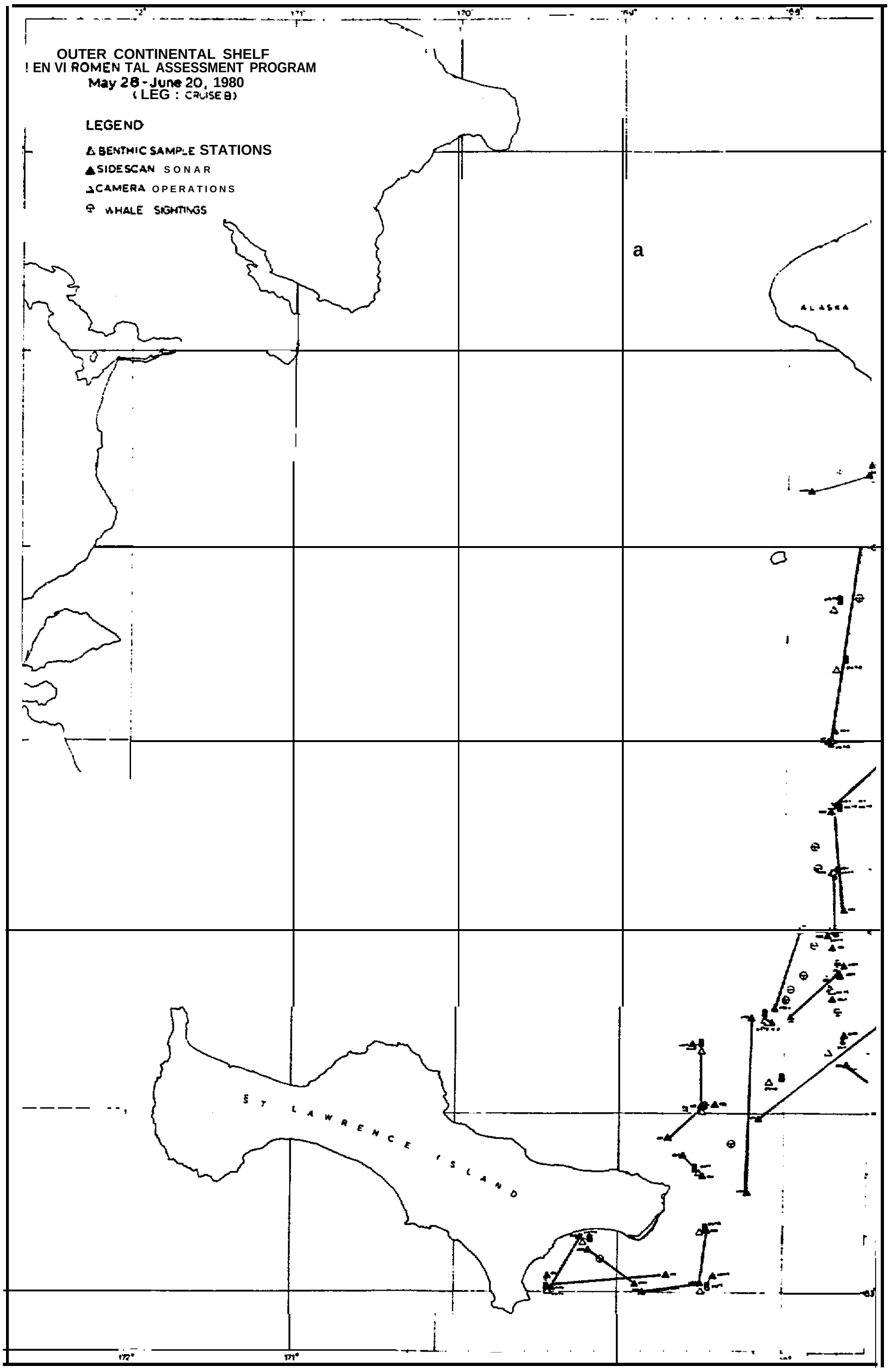


Figure *8.* Gray whale sampling stat ions - leg I, May 28-June 20, 1980.

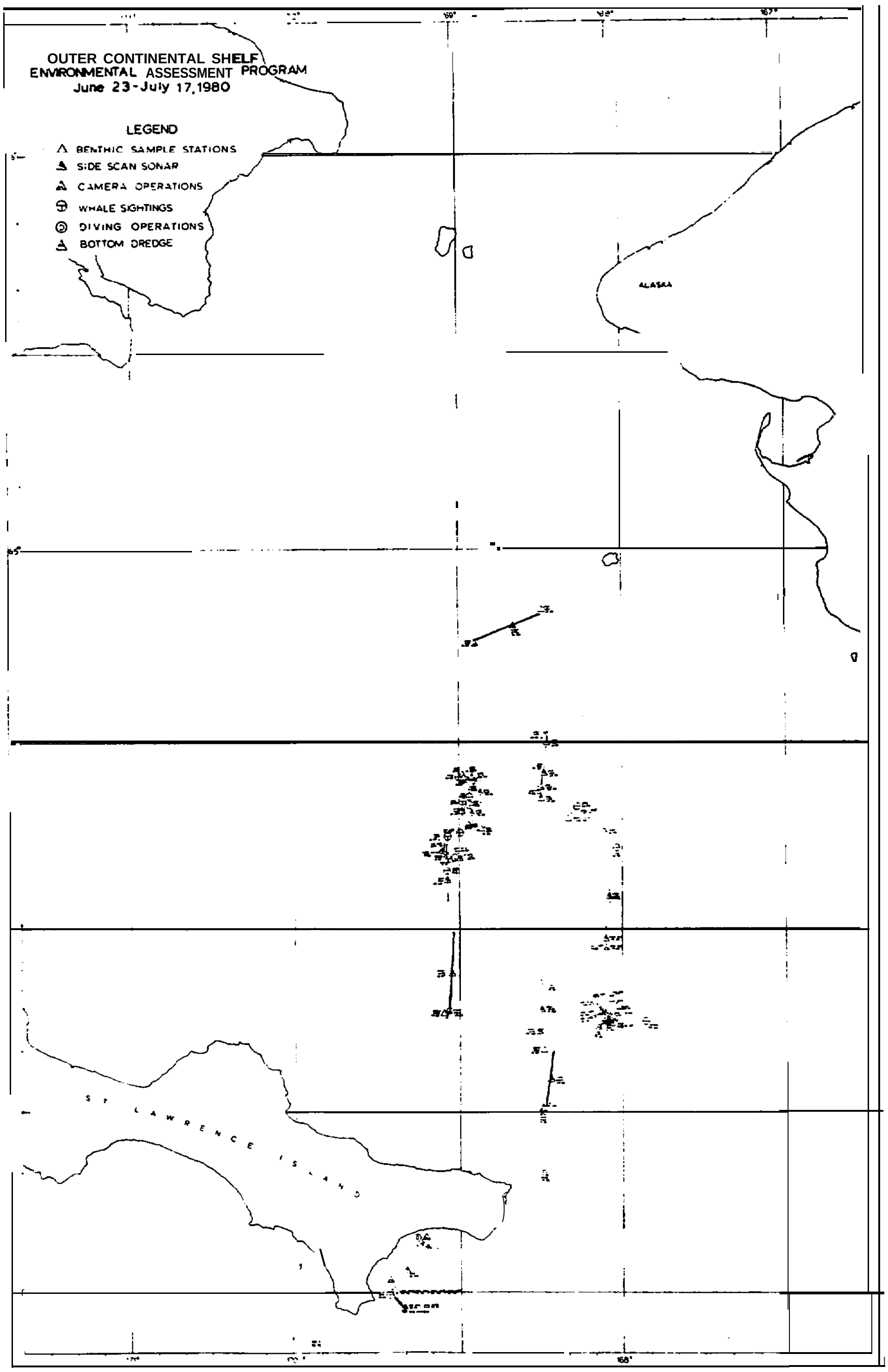


Figure 9. Gray whale sampling stations - Leg II, June 23-July **17,** 1980.

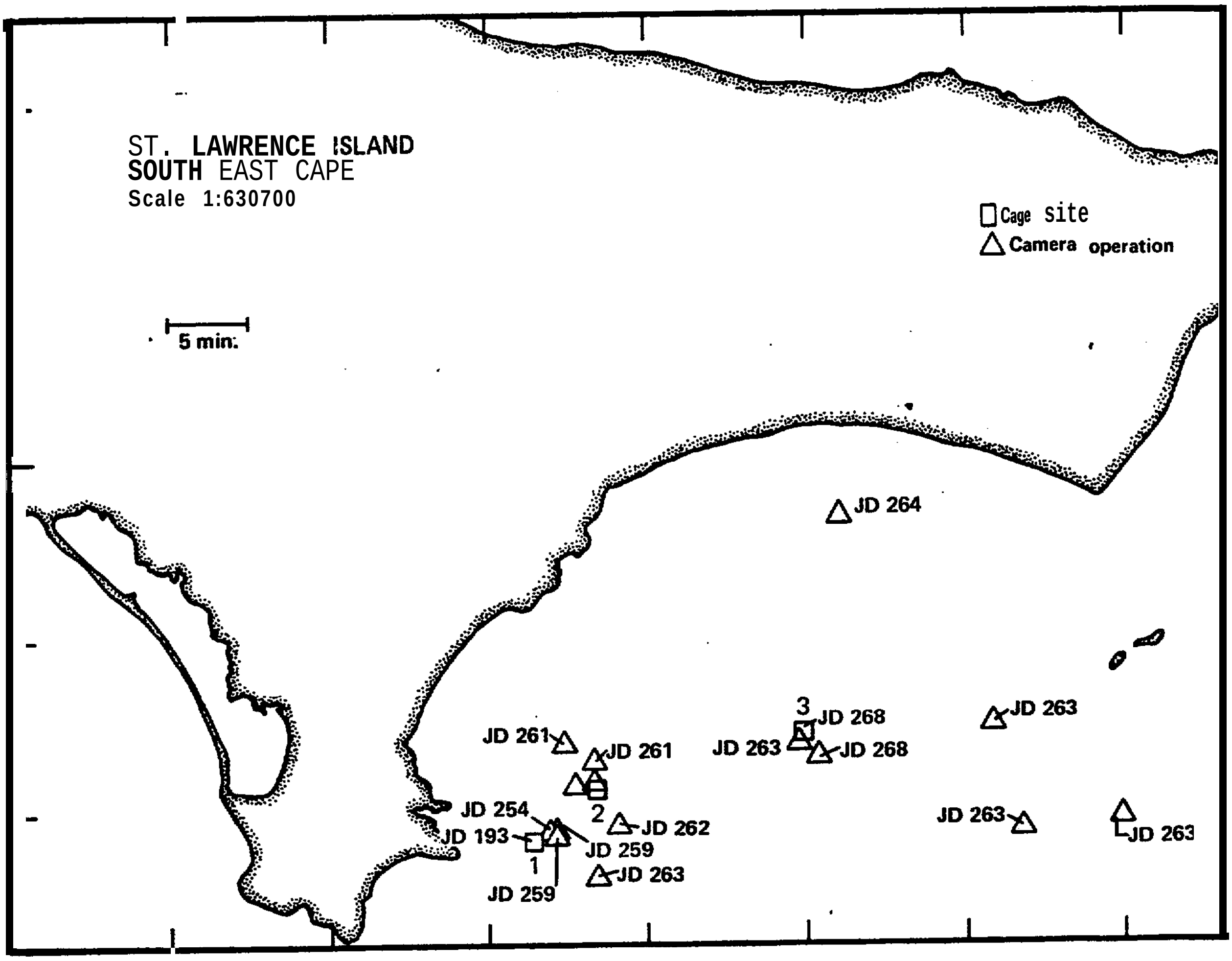


Figure 10. Gray whale sampling stations - Leg V, 10-30 September 1980.

of feeding gray whales were difficult because it was impossible to identify individuals. Dive times were obtained by spotting one animal, and circling it until the animal resurfaced. Observations were continued for half an hour and then the helicopter moved to another area. Unfortunately, there was no way of knowing whether two or more animals were surfacing in tandem. In six cases, we collected dive times on what we thought were solitary whales, and a second whale surfaced. In these cases, only respiration rates and not dive times were obtained from animals which had just surfaced after a feeding bout. Unless the animals are marked, it is very difficult to obtain meaningful diving data on feeding gray whales in offshore waters. One way to circumvent the difficulties of multiple feeding whales would be to attach a streamer tag to animals which would be visible to observers in the air, or to conduct observations from shore.

## Side-scan Sonar

Side-scan sonar techniques have been successfully used in geological research to detect small topographic changes in the ocean bottom. We planned to use the same methods to detect and describe disturbances made by whales in the bottom sediments. Once the type of disturbance was identified, we planned to assess the impact made by whales on an area by quantifying the number of feeding scrapes.

Two separate systems were used in this endeavor. On leg II, an EG + G side-scan system[2] operated by the U.S. Geological survey was used. It was outfitted with a 105 khz transducer. These records belong to the U.S. Geological Survey, Menlo Park. On the second leg, we employed a Klein and Assoc. side-scan system operated by personnel from Jon B. Jolly Inc. and outfitted with a 500 khz or 100 khz fish. The recording track width was set at 50 m on both legs, towing speed was 5-7 kts. The side-scan sonar was towed a total of 787 km, covering our study site and the nearshore waters of St. Lawrence Island.

## Underwater Video Camera

The video camera proved to be our most useful tool. We originally intended to use it solely to find whale-made disturbances but by the last cruise its function has expanded. We routinely towed the camera through a new area, which allowed us to plan our dives and choose our sampling sites. By routinely towing the camera through a new area, we were able to plan our dives and choose our sampling sites. By verifying what we observed on the camera with grab samples, we were able to categorize communities by sight. Most importantly, the video footage gave us insights into the variability in the community produced by the bottom depressions, and the importance of predators other than whales.

The camera was a Panasonic black and white newvicon camera in an underwater housing. It was equipped with a 16 mm lens and quartz halogen lights. The assembly was mounted on a towing frame which fixed the camera position approximately 30 cm above the substrate, with a field of view of 0.75 m by 1.2 m. We continually refined the system, and by the last cruise we had devised a method of releasing a float from the camera assembly to mark features we viewed on the video screen. This enabled the divers to investigate specific sites. The camera was on the bottom for a total of 34.4 hours at 43 locations.

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2 Reference to trade names does not necessarily imply endorsement by the National Marine Fisheries Service.

## Benthic Sampling

A scuba diving operation was conducted to sample the benthic community inside and outside of targeted bottom disturbances which we believe to arise from foraging gray whales. The disturbances were separated into two conformations; those that were long, sinuous and narrow we termed furrows and those that were round or elliptical we designated pits. There were six divers on each of the legs. A total of 22 dives were made in water depths varying from 23-40 m (75-130 ft.). Diving conditions on leg II were superior to those on leg I. Visibility was generally poor but averaged 1.5m. The water was colder than predicted; on leg I, bottom temperatures hovered around -1° c.

The core samplers used by the divers to sample the infauna were #10 tin cans (0.188 $m^2$) with removable plastic lids. Samples were washed on 0.5 mm screens. In addition to collecting samples, divers removed the infauna from 1 $m^2$ plots for use in the re-colonization experiments, took photographs, and measured pit dimensions. The divers also helped deploy and anchor three 3.7 x 4.9 m structures, fabricated of 45.7 cm (1' 1/2") galvanized steel pipe, which we used to mark our study areas for long term studies of the benthic communities.

Both a 0.025$m^2$ box corer and a 0.1 $m^2$ Smith-MacIntyre grab were used to sample the Chirikov bottom. In all, 130 samples representing 30 sites were collected. Samples were washed on 1 mm and 0.5 mm screens, relaxed in $MgCl_2$, fixed in a 5% formalin solution, and preserved in 70% alcohol. In addition to those collected on our own cruises, samples were collected from the more westerly portion of the study area by scientists on USCGS icebreaker *Polar Star* during June using a 0.1 $m^2$ Van Veen grab. Because of the difference in gear, these samples are not entirely compatible with our own data, but provide distribution information on community types. Taxonomic analysis of the Smith-McIntyre samples is underway and expected to be completed by the end of March. All the infaunal data provided in this report are from the cores collected by scuba divers.

# RESULTS

## Time Budgets: Gray Whale Dive Profiles

Table 1 provides time budget (dive profile) information gathered in 1977 by Braham and by Nerini during the summer 1980 study.

## Feeding Furrows, Pits and Other Bottom Features

Side-scan records from leg I in areas where we sighted whales display series of irregular furrows. The furrows varied in length from 3 to 30 m and were 0.5-1 m wide. They were only present in areas where whales were sighted. Due to their irregular, twisting shape and their size, (Fig. 11) the origin of these bottom features is thought to be biogenic. Scientists at the U.S. Geological Survey suggested whales were the most likely cause of the furrows (H. Nelson, USGS, pers. comm.).

During the second leg, more varied furrow shapes were seen (Fig. 12) and we noted much of the Chirikov basin was pitted. The bottom appears to be pock-marked by shallow depressions varying in size from 2 to 10 m in diameter (Table

TABLE 1.--Dive profiles of foraging gray whales.

| Whale ID#[1] | Surface time in seconds | Average time between breaths in seconds | Duration of dives | Average duration of dives |
|---|---|---|---|---|
| 01 | 15 | 16.15 | | 4 min. 38 sec. |
| | 15 | | | |
| | 08 | | | |
| | 08 | | | |
| | 14 | | | |
| | 27 | | | |
| | 19 | | 4 min. 58 sec. | |
| | 06 | | | |
| | 12 | | | |
| | 14 | | | |
| | 25 | | | |
| | 22 | | 1 min. 54 sec. | |
| | 14 | | | |
| | 17 | | | |
| | 12 | | | |
| | 23 | | | |
| | 21 | | 6 min. 14 sec. | |
| | 11 | | | |
| | 33 | | | |
| | 27 | | | |
| | 13 | | | |
| | 09 | | | |
| | 08 | | | |
| | 17 | | 4 min. 45 sec. | |
| | 10 | | | |
| | 20 | | | |
| 02 | 15 | 18.25 | | |
| | 15 | | | |
| | 18 | | | |
| | 25 | | | |
| 03 | 08 | 11.66 | | |
| | 12 | | | |
| | 15 | | | |
| 04 | 12 | 19.8 | | |
| | 14 | | | |
| | 15 | | | |
| | 38 | | | |
| 05 | 40 | 34.33 | | |
| | 39 | | | |
| | 24 | | | |

TABLE 1.--Dive profiles of foraging gray whales--continued.

| Whale ID# | Surface time in seconds | Average time between breaths in seconds | Duration of dives | Average duration of dives |
|---|---|---|---|---|
| 06 | 14 | 26.25 | | |
| | 18 | | | |
| | 38 | | | |
| | 35 | | | |
| 07 | 31 | 22.66 | | |
| | 18 | | | |
| | 19 | | | |
| 29-1 | 90 | 88.8 | | |
| | 147 | | | |
| | 60 | | | |
| | 86 | | | |
| | 68 | | | |
| | 129 | | | |
| | 33 | | | |
| | 128 | | | |
| | 22 | | | |
| | 125 | | | |
| 29-2 | 52 | 57.6 | | |
| | 56 | | | |
| | 77 | | | |
| | 61 | | | |
| | 51 | | | |
| | 45 | | | |
| | 83 | | | |
| | 36 | | | |
| 30-3 | 19 | 58.5 | | 3 min. 53 sec. |
| | 37 | | | |
| | 13 | | | |
| | 127 | | | |
| | 93 | | | |
| | 70 | | | |
| | 86 | | | |
| | | | 3 min. 27 sec. | |
| | | | 3 min. 36 sec. | |
| | 23 | | | |

TABLE 1.--Dive profiles of foraging gray whales--continued.

| Whale ID# | Surface time in seconds | Average time between breaths in seconds | Duration of dives | Average duration of dives |
|---|---|---|---|---|
| 30-4 | 126 | 78.1 | | 2 min. 43 sec |
| | 127 | | | |
| | 134 | | | |
| | 91 | | | |
| | | | 2 min. 43 sec. | |
| | 57 | | | |
| | 85 | | | |
| | 39 | | | |
| | 47 | | | |
| | 25 | | | |
| | 47 | | | |
| | 81 | | | |
| 30-5 | 63 | 83.66 | | |
| | 150 | | | |
| | 135 | | | |
| | 45 | | | |
| | 110 | | | |
| | 50 | | | |
| | 95 | | | |
| | 65 | | | |
| | 40 | | | |
| 1-6 | 40 | 59.89 | | |
| | 87 | | | |
| | 27 | | | |
| | 91 | | | |
| | 140 | | | |
| | 19 | | | |
| | 21 | | | |
| | 44 | | | |
| | 70 | | | |
| 2-7 | 31 | 34.29 | 3 min. 27 sec. | 3 min. 56 sec. |
| | | | 3 min. 38 sec. | |
| | 18 | | 3 min. 55 sec. | |
| | 16 | | | |
| | | | 3 min. 15 sec. | |
| | 20 | | | |
| | 110 | | | |
| | 10 | | | |
| | 35 | | | |

TABLE 1--- Dive profiles of foraging gray whales--continued.

| Whale ID# | Surface time in seconds | Average time between breaths in seconds | Duration of dives | Average duration of dives |
|---|---|---|---|---|
| 2-8 | 11 | 17.33 | | 4 min. 12 sec. |
| | | | 3 min. 37 sec. | |
| | 27 | | | |
| | 20 | | | |
| | | | 4 min. 55 sec. | |
| | 12 | | | |
| | 14 | | | |
| | | | 3 min. 50 sec. | |
| | 20 | | | |
| 2-9 | 18 | 26.6 sec. | | 3 min. 47 sec. |
| | 87 | | | |
| | | | 3 min. 21 sec. | |
| | 22 | | | |
| | 23 | | | |
| | | | 4 min. 51 sec. | |
| | 15 | | | |
| | 25 | | | |
| | 23 | | | |
| | | | 2 min. 13 sec. | |
| | 17 | | | |
| | 17 | | | |
| | 19 | | | |
| 2-10 | 24 | 47.53 sec. | | 2 min. 48 sec. |
| | 52 | | | |
| | | | 2 min. 15 sec. | |
| | 20 | | | |
| | 33 | | | |
| | 92 | | | |
| | 60 | | | |
| | 35 | | | |
| | | | 2 min. 42 sec. | |
| | 23 | | | |
| | 18 | | | |
| | 104 | | | |
| | 15 | | | |
| | 66 | | | |
| | 63 | | | |
| | 27 | | | |
| | 81 | | | |

TABLE 1.--Dive profiles of foraging gray whales--continued.

| Whale ID# | Surface time in seconds | Average time between breaths in seconds | Duration of dives | Average duration of dives |
|---|---|---|---|---|
| 2-11 | 40 | 42.07 | | 2 min. 44 sec. |
| | | | 3 min. 03 sec. | |
| | 82 | | | |
| | 11 | | | |
| | 23 | | | |
| | 39 | | | |
| | 151 | | | |
| | 22 | | | |
| | 12 | | | |
| | 36 | | | |
| | | | 2 min. 50 sec. | |
| | 15 | | | |
| | 18 | | | |
| | 25 | | | |
| | 25 | | | |
| | 90 | | | |

[1] Numbers 01-07 collected May 28-July 17 1980 in the Chirikov Basin; #29-1 to 2-11 collected June 29-July 11, 1977, off SE Cape, St. Lawrence Island.

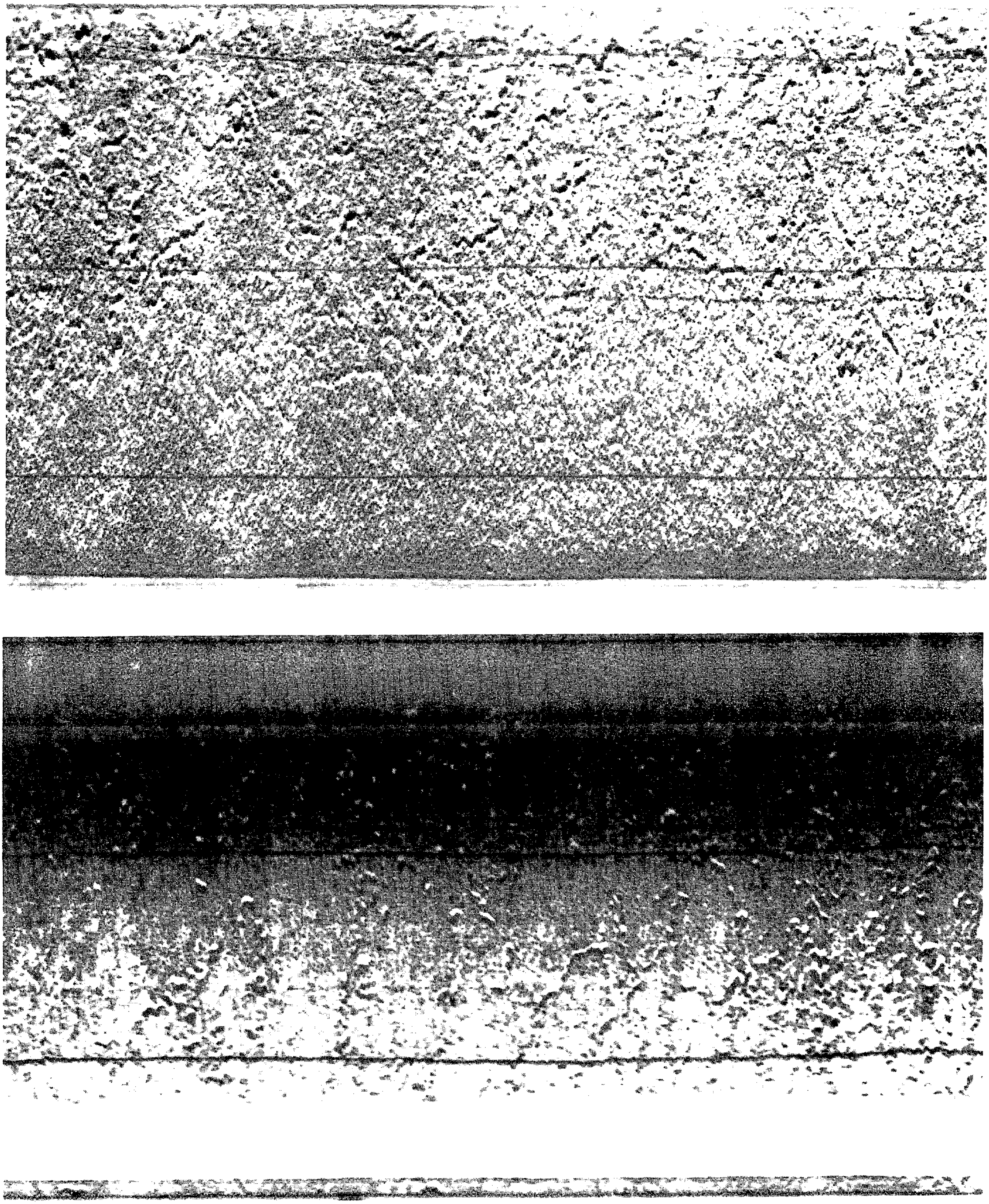


Figure 11. "Furrows" as depicted on 100 khz side-scan sonar records. Towing speed was 5.2 kts.

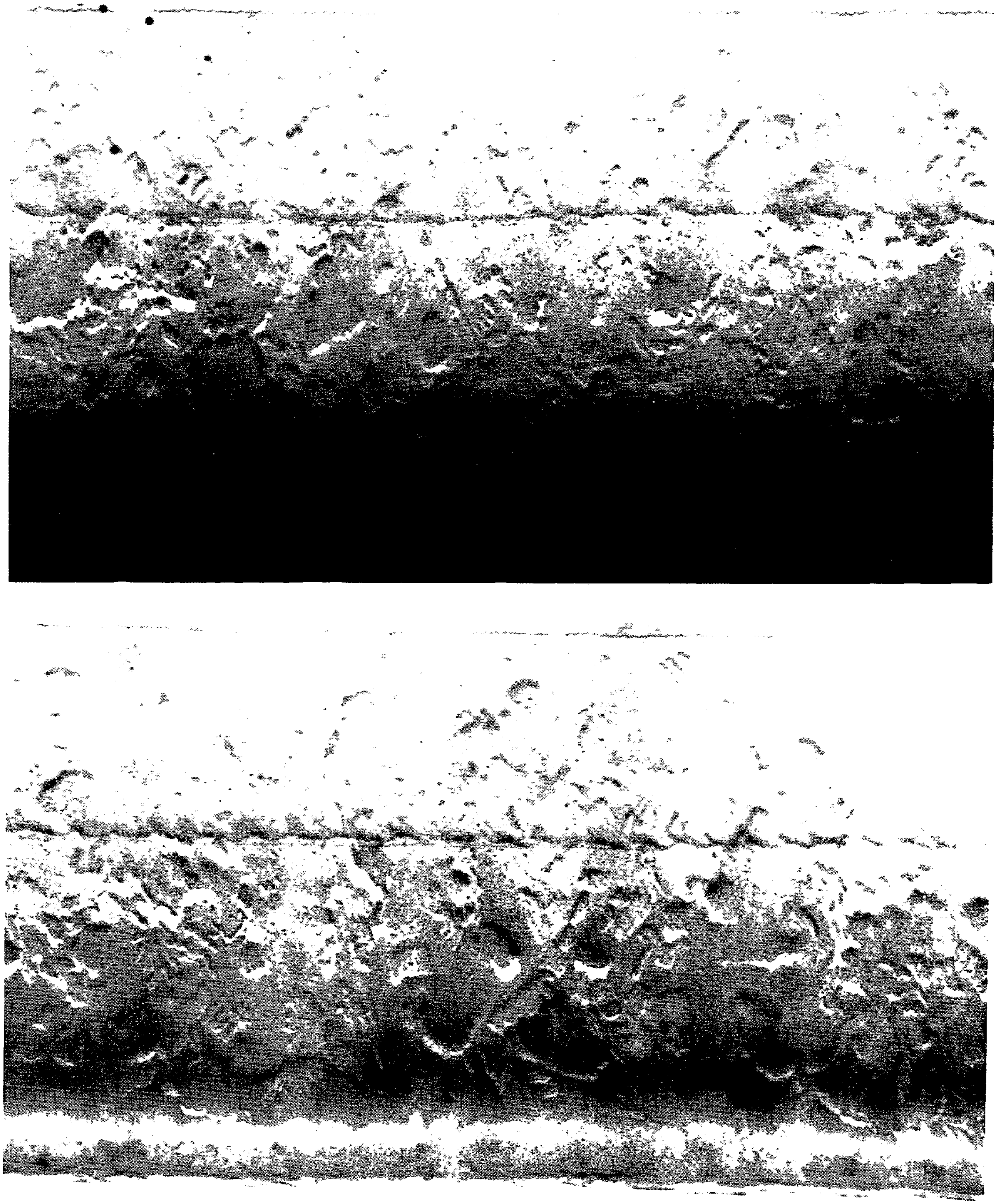


Figure 12. Bottom depressions depicted on 500 khz side-scan sonar records. Towing speed was 2.9 kts.

2). Although pits were evident over the entire northern Bering Sea, they appeared to be more pronounced, that 1s, both more abundant and larger, near the center of our study **area.**

The spatial distribution of the furrows **is less** clear than that of the pits. That is, there is no obvious area where furrows dominate the bottom features. Furrows appeared only in areas we presumed to be used by whales but whales *were* not always present. On one occasion, we made several passes through a small pod of feeding whales ( '5 animals) while towing the side-scan transducer and saw no evidence of furrows with either the 100 or 500 **khz** fish.

Ice scour was found as expected near the northeast end of St. Lawrence Island. There was no evidence of scour from nearshore fast ice in the eastern bight of the island, nor in the central **Chirikov** Basin.

The bottom depressions are of interest because even slight topographic unevenesses in the sediments **can** create micro habitats into which organisms will distribute themselves non-randomly. Thus the pits **almost** certainly affect, **benthic** community structure. We classified regions of the Bering Sea by the density **and** magnitude of the pits and by the visible **infaunal** organisms. We recorded general slope of the pit sides; **epifaunal** organisms and presence of dead shells which led us to subjective conclusions regarding the northern Bering Sea **benthos.** The most pronounced pits, that is, those which were deepest, had the steepest sides, and whose bottoms were strewn with **shells,** seem to be located in the central northern Bering Sea - the same region **whales** appear to be actively feeding.

## **Benthic** Infauna

### Species, Composition and Densities

**The** dominant (i.e. numerically and by biomass) **organism** in **all** but 3 of our samples was **Ampelisca macrocephala.** Densities ranged from 400-22,450 **individuals/m$^2$ (Table** 3). The higher values **were** in the area where **we** consistently saw feeding whales during leg 11 **(near** Station 21). The corresponding **amphipod** biomass was 94gm/m$^2$ to 500 **gm/m$^2$.** Because on the fall cruise we could not **re-locate** those sites we had marked **in** the spring, we cannot directly compare seasonal biomass levels.

The size structure of the **amphipod** population shifted only slightly with the season (Fig. 13). **Gravid** females were found in both seasons but recently hatched animals (O-3 mm) were found solely in the spring. The modal size class in all seasons was the 5-7 mm class although in the autumn, the distribution becomes hi-modal as the 9-11 mm **class** increases in frequency. Large individuals (>17 mm) were only found inside pits in the spring but this trend was not found in the autumn data. There is otherwise no significant difference between size classes inside or outside of the **pits.**

### Ecological Attributes of the Bottom Features

We assume the topographical variation in the benthos may create differences in communities. If, as we thought, the pits were formed by foraging whales, then one **might** initially expect a depauperate **infauna** within the depression

TABLE 2.--Pit dimensions.

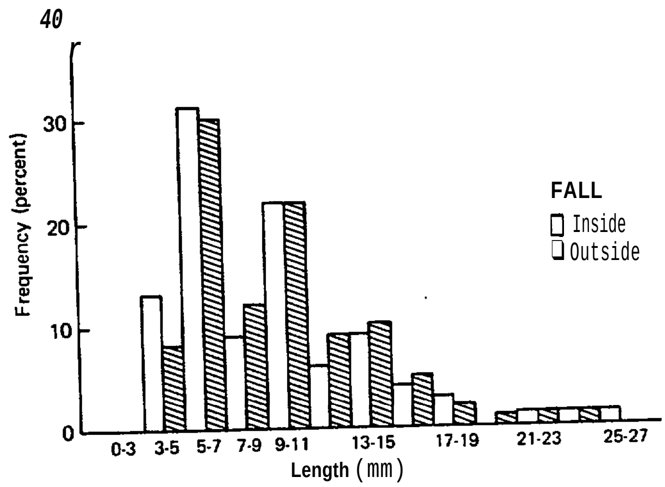
| Axis 1 (m) $A_1$ | Axis 2 (m) A2 | Depth (m) | Approx. area($m^2$) A= $\frac{(A_1 A_2)}{4}$ | Index area x depth |
|---|---|---|---|---|
| .61 | 0.61 | .13 | 0.30 | 0.039 |
| * 1.0 | 1.5 | .40 | 1.18 | 0.472 |
| * 1.0 | 1.5 | .40 | 1.18 | 0.472 |
| * 1.0 | 1.5 | .20 | 1.18 | 0.236 |
| 1.0 | 1.0 | .10 | 0.8 | 0.08 |
| 2.3 | 0.9 | .19 | 1.63 | 0.31 |
| 0.64 | 0.71 | .08 | 0.36 | 0.03 |
| 2.2 | 0.9 | .15 | 1.56 | 0.234 |
| 0.76 | 0.9 | .20 | 0.54 | 0.11 |
| * 1.2 | 0.76 | .20 | 0.72 | 0.14 |
| 2.0 | 2.0 | | 3.14 | |
| * 2.0 | 3.0 | | 4.71 | |
| * 1.5 | 3.0 | .10 | 3.53 | 0.34 |
| 1.7 | 1.7 | .18 | 2.27 | 0.41 |

* Denotes $0.019 m^2$ sample taken from within measured pit by divers.

Table. 3--Average amphipod abundances inside and outside of pits and partitioned by season.

| | | | | |
|---|---|---|---|---|
| Avg.# *A. macrocephala*/$m^2$ | (Spring) | 5934.6 | S.D. = 5000.2 | n=40 |
| | (Fall) | 5025.4 | S.D. = 2640.5 | n=34 |
| | (inside) | 5557.6 | S.D. = 4435.5 | n=38 |
| | (outside) | 5694.8 | S.D. = 3756.9 | n=33 |
| Avg. gms *A. macrocephala*/$m^2$ | (inside) | 137.6 | S.D. = 39.6 | n= 16 |
| | (outside) | 105.9 | S.D. = 77.3 | n= 14 |
| Avg. gms total Amphipods/$m^2$ | (inside) | 190.9 | S.D. = 59.2 | n=16 |
| | (outside) | 199.5 | S.D. = 94.5 | n= 14 |
| Avg.# A. *macrocephala*/$m^2$ | Spring | | | |
| | (inside) | 5165.4 | S.D. = 5609.3 | n=22 |
| | (outside) | 6874.7 | S.D. = 3986.6 | n= 18 |
| | Fall | | | |
| | (inside) | 6097.0 | S.D. = 1985.5 | n=16 |
| | (outside) | 4278.9 | S.D. = 3004.2 | n= 15 |

S.D. = standard deviation
n = number of observations



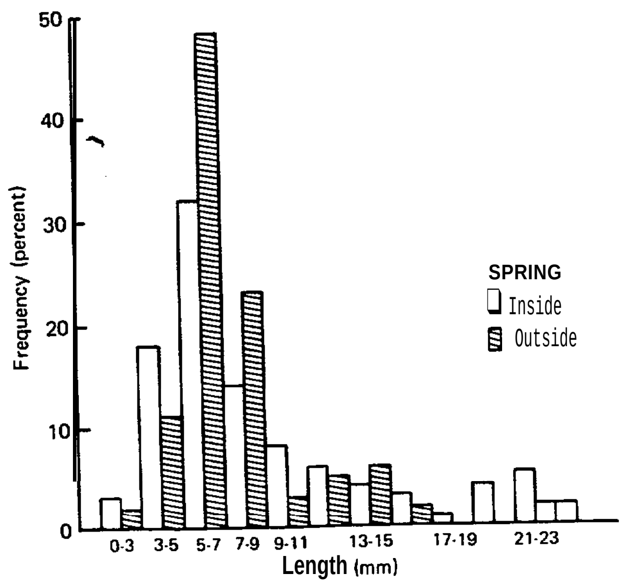




Figure 13. Length frequency histograms of *Ampelisca macrocephala*.

left by a feeding whale. Shortly after its creation, one might predict first an increase in scavenging organisms which subsist on detritus collecting in the pits, followed by the more sedentary tube-builders. This successional pattern is one commonly documented in disturbed areas (Pearson and Rosenberg, 1978; McCall, 1977; Oliver and Slattery, 1976). Since congeneric species may display similar colonizing and feeding strategies, we combined the species data and analyzed by genus using a Wilcoxon-Mann Whitney rank-sum test. There were only three instances where the abundance of genus inside a pit was significantly different from that found outside a pit (Table 4). All three genera were tube-building animals. The size (and inferred age) of the pit was not considered in this analysis due to small sample sizes with increased partitioning of the data.

In addition to species comparisons, we also measured the volume of tube material found in the sorted bottom samples inside and outside of pits (Fig. 14). Since we expect tube-dwelling organisms such as the Ampelisca species to be less adroit at colonizing an area, we expected tubal material to be less abundant inside the presumably defaunated pits. There was no significant difference (t-test, P >.05) in our data but again age of the pit was not considered.

To investigate temporal changes in the infaunal pit community corresponding to the time elapsed from the initial disturbance, we assigned relative ages to the sampled pits based on their area, estimated depth, slope of the sides and biological information such as the presence of dead shells or exposed worm tubes. By then, focusing on groups of organisms, i.e. representative families, we hoped to see successional trends in colonization of the pits. The families we chose to focus on were the Ampeliscidae (comprised of Ampelisca macrocephala, A. eschricti, A. birulai, and Byblis sp.); the Lysianassidae (Anonyx nugax and Orchomenella minuta); and the Corophiidae and their relatives (Protomedeia fasciata, Corophium sp., Photis sp.).

The Ampeliscidae are sedentary, tube-dwelling detritus feeders (Kanneworff 1965) as are the members of the Corophiidae we chose. Whereas the lysianassids are active, wide-ranging scavengers. Because of these attributes, we expected the three groups would dominate the pit community at different times relative to the age of the pit. That is, we predicted that in newly exposed sediments, the recent pits, there would be an increase in the lysianassids. Similarly, we reasoned that the less active tube-dwellers would be in low abundance in the recent pits but would subsequently increase in abundance until their densities inside the pits were indistinguishable from the densities outside of the old pits.

For this analysis, data from spring and autumn were pooled because of small sample sizes (Fig. 15). Only in the Lysiannasids were the means from the three ages of pits significantly different (one-way ANOVA P <.05). The plots presented include mean abundance and standard deviation. As the relatively sedentary tube-builders may be more active colonizers during the spring before their offspring hatch, we may have obscured trends in the paired samples by combining the seasonal data. In addition to unaccountable seasonal differences in dispersal strategies this test was based on inferred ages of pits which further complicates the interpretation.

## Recolonization

As a controlled experiment, we created our own pits to document the benthic community change over time in a cleared area. By understanding this process,

TABLE 4---Genera abundance inside + outside of pits (significant difference detected by Wilcoxon-Mann-Whitney rank-sum test).

| Genus | Species | Leg 2 (summer) | n | Leg 5 (fall) | n |
|---|---|---|---|---|---|
| Ampelisca | 3 | ** outside | 18 | n.s. | 1.5 |
| Anonyx | 2 | n.s. | 18 | n.s. | 15 |
| Orchomene | 2 | n.s. | 15 | n.s. | 9 |
| Protomedefa | 2 | * outside | 18 | *** inside | 15 |
| Photis | 1 | n.s. | 15 | n.s. | 11 |

*** denotes significant at .01 level
** denotes significant at .05 level
* denotes significant at .1 level
n.s. = not significant
n = number of ( )

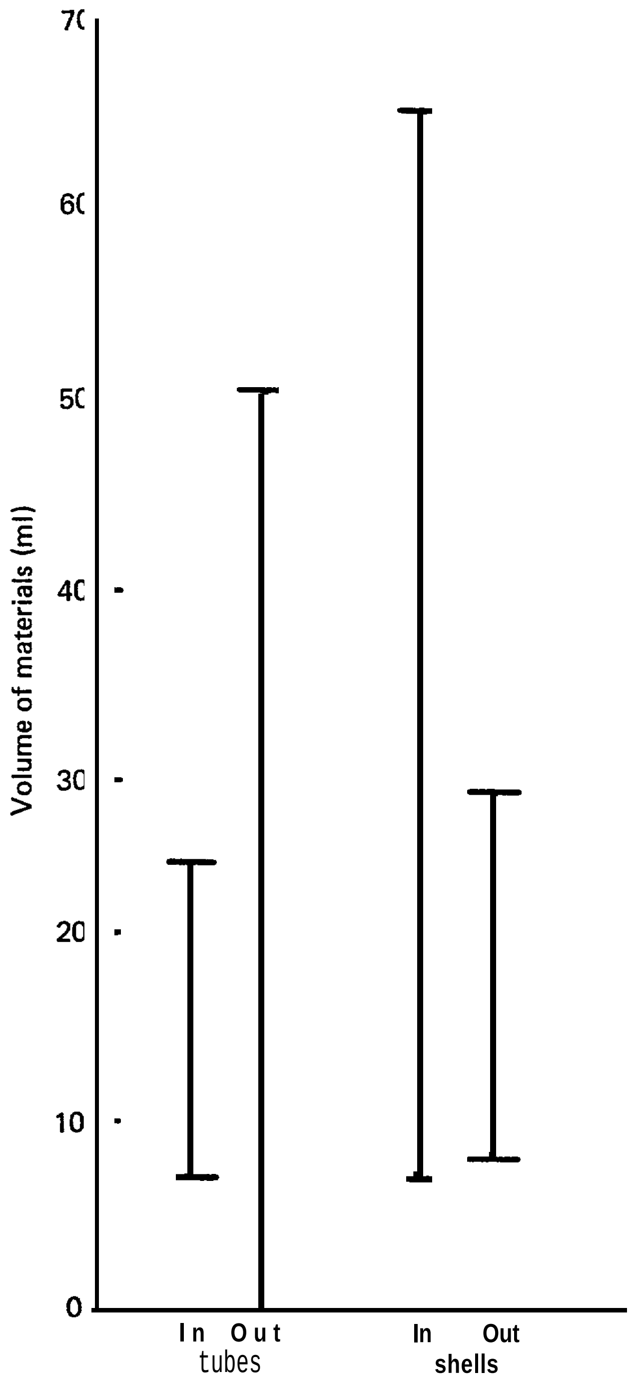



Figure 14. **Volume** of infaunal tubes and shell debris in 0.019 $m^2$ cores collected by divers inside and outside of bottom depressions. (N = 15 inside; N = 13 outside).

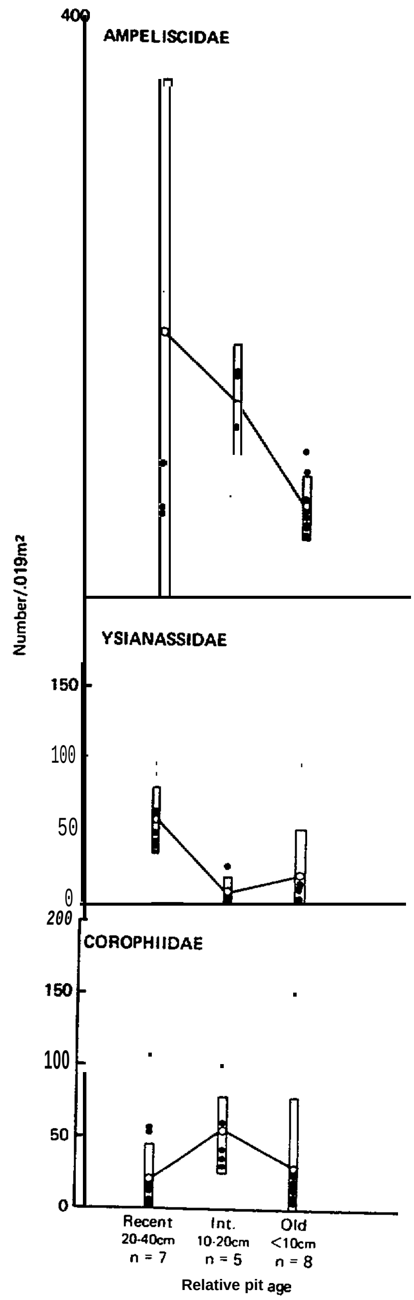



Figure 15. Abundance patterns of selected amphipod families inside pits, Pit "age" is subjectively assigned as indicated in the text.

we can better interpret data from our other samples. Two $1m^2$ patches were cleared of the top 10 cm of sediment using a pneumatic lift. Both patches were established near Southeast Cape St. Lawrence Island in September. The plots were sampled immediately after clearing the area, the following day, and six days later. Abundance of Anonyx nugax, Orchomenella minuta, Ampelisca macrocephala and Protomedeia fasciata are plotted in Fig. 16. As expected, there was a sharp increase in abundance of scavenging Lysiannasids (Anonyx and Orchomenella) by day 1 with a corresponding sharp drop in Ampelisca. This pattern corroborates the sequence we have tentatively documented in the natural system.

## DISCUSSION

It became clear by leg 11 that we would be unlikely to see an actively foraging whale because of underwater visibility, dive time limitations and the paucity of whales on the study site during early July. Therefore we were unable to quantitatively describe how whales feed, how much they consume and where they chose to feed.

Our first goal, that of definitely establishing the mechanism by which whales feed, was patently impossible. However, for an animal the size of a whale to consume infaunal organisms without discriminating between prey, any feeding mechanism would entail a wholesale removal of sediment. Since sand and gravel are commonly found in gray whale stomachs, usually in small quantities, and because we see "mud" plumes emanating from foraging whales, we assume the feeding activities of the whales change the infaunal community by removing community dominants and by physically disturbing the substrate. Quantification of whale food consumption may only be possible by carefully monitoring the traces left in the bottom by foraging whales. Other investigators in soft-bottom systems have similarly examined the physical and community changes created by a benthic predator (VanBlairicom 1978).

Examining the small scale bathymetry of the northern Bering Sea both in areas where whales were present and where they were not, the ubiquitous features are the depressions or pits. The "furrows" mentioned earlier and apparent on the side-scan records were well correlated with the presence of whales but much rarer than the pits. In fact, we were unable to locate any "furrow'" with divers. The cause of the furrows and pits is still unknown.

The furrows may represent a direct impingement of the whale on the bottom, whereas the pit may be shaped by several factors. Over most of the area which we sampled, the surface sediment was a cohesive muddy tube mat underlain by fine sand. Given such a structure one might expect to see wave and current scour only in those areas where there was a break in the surface tube mat. We postulate that a feeding whale must break up the tube mat, leaving the surrounding area vulnerable to wave scour. This may be analogous to the observations of Fager (1964) who noted that dense polychaete beds were susceptible to destruction by wave surge only after an initial intrusion through the cohesive sediments. Wave scour near objects protruding through the sediments is a well known geologic process (Larsen et. al. 1979) and scouring, added to the initial whale disturbance, would produce shallow symmetrical features such as the pits.

Subjectively, the abundance and the type of pits changed with the area. That is, in the central Chirikov basin at our deepest dive sites, we encountered

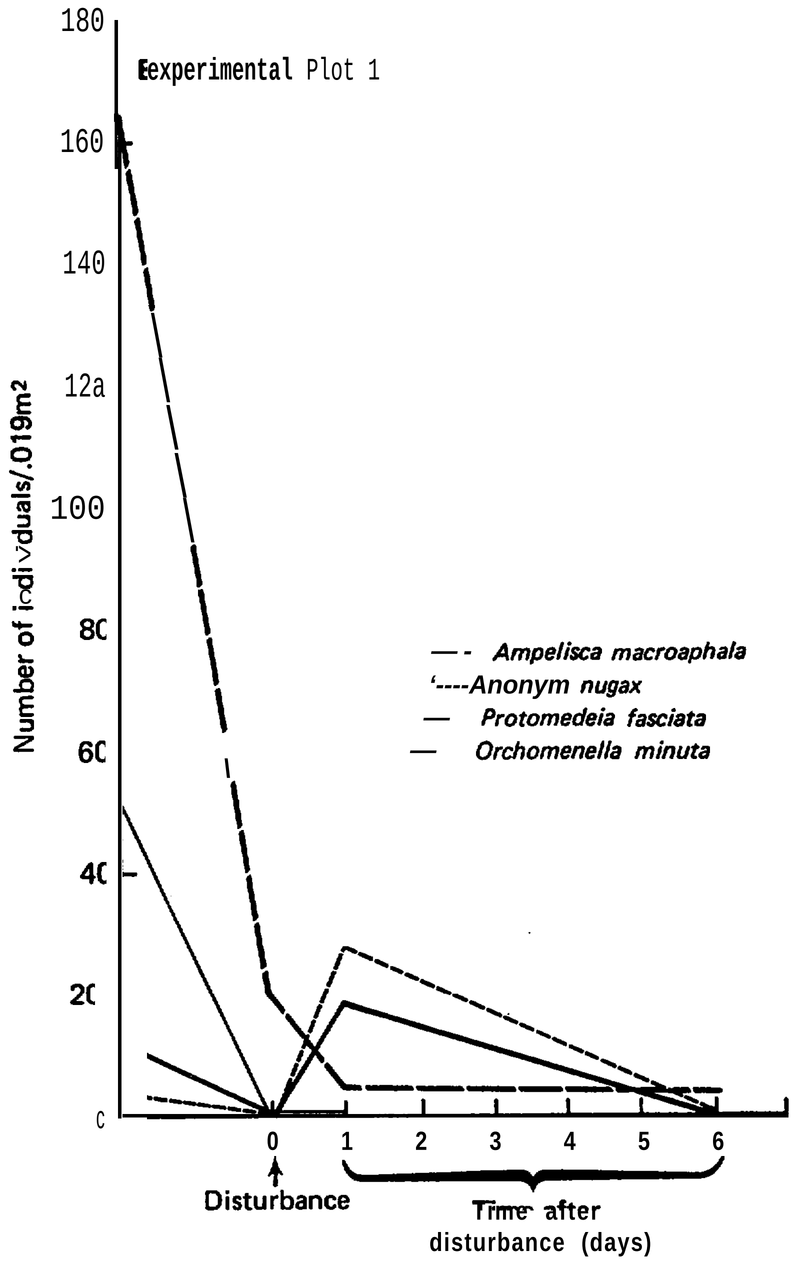



Figure 16. Species abundance over time in 1 $m^2$ plot after experimental defaunation. O indicates the day the plot was cleared of infaunal organisms and the top 10 cm of sediment.

the deepest and largest pits, the highest densities of amphipods and the greatest number of feeding whales. Admittedly, it is too early in the study to produce a concrete correlation between feeding whales and the appearance of pits but the hypothesis is appealing and reasonable. Since regions of abundant pits are patchy, we may also find that prime whale feeding habitat is correspondingly patchy.

The benthic infaunal data seem to support the hypothesis that pits are defaunated patches which are in various successional stages possibly returning to a high density, tube-building amphipod community. Our data (i.e. a six day time sequence) on the time required for a cleared patch to be recolonized is too scanty to predict how rapid the recovery is. However, the rate of return to original community state is undoubtedly heavily influenced by patch size and season of disturbance as it is in other bottom systems (McCall 1977; Helling 1973; Sutherland 1974; and Gray 1977) and these are factors we have not been able to test. Long-term experiments documenting changes in communities of various sized pits both in the Chirikov and off Southeast Cape should provide the necessary information on the regeneration time of the community.

Putting this preliminary information together in a rudimentary fashion, we can compute very gross estimates of gray whale consumption. We must caution that the assumptions behind the ensuing calculations are considerable at this stage of the research. However, one of our objectives was to estimate feeding rates of gray whales. In-the most productive reaches of the northern Bering Sea the mean amphipod densities outside of pits are on the order of $9,600/m^2$ with a corresponding biomass of 400 $g/m^2$. Average area of a pit in this region was a minimum of $0.81/m^2$. By simply multiplying, we estimate 324 gms of amphipods may be removed per pit. Further field research is necessary to determine how accurate or meaningful this estimate is.

## CONCLUSIONS

The data collected during this first year of research were less than hoped for and thus our conclusions are preliminary. The research has focused on processes that will take several years to understand. In addition, we feel that our initial year was in large part a feasibility study to determine which approaches were possible what experiments could be attempted, and what questions could be addressed. In addition, and perhaps of greatest importance, this past year helped us determine which questions warrant further investigation.

We have reached the following conclusions regarding gray whale feeding ecology in the Bering Sea:

1. Whales seem to concentrate over areas of highest amphipod density, that is, in the Chirikov Basin. Their summer distribution is linked to the regions with dense prey assemblages.

2. Gray whales are omnivorous; their stomach contents appear to be random samples of the community upon which they feed.

3. There is large variation in the "quality" (as we assess it) of amphipod communities and in their corresponding usage by whales.

4. The bottom depressions seen across the Chirikov basin are possibly produced by foraging whales.

5. It will be possible to study regeneration time of a community by observing successional patterns in experimentally cleared areas and natural depressions.

## Recommendations

1. A main question of our subsequent research is "*do whales create the bottom depressions?". Since the characteristics of the bottom sediments are important to the evaluation and maintenance of the pits, investigation of sediment properties such as cohesiveness and resistance to scour will be helpful.

2. Without being able to see a whale foraging on the benthos, we need evidence that the production of bottom depressions is correlated with the presence of whales. By quantifying the number and size of pits present at the start of the summer and comparing that to what we see later in the season over precisely the same transect, we should be able to determine the magnitude of the gray whale impact on the sediments. This work would require a refined camera system which perhaps has a compass in the viewing screen and a mechanism to gauge depth and size of depressions. .

3. We feel that any further work in this project should be conducted from a smaller vessel. A large vessel cannot maintain its steerage while moving at the slow speeds needed for the video camera operations. In order to quantify bottom features, it is essential to be able to run a charted course while towing the camera.

4. To further our understanding of the successional nature of the bottom depressions, we would continue the experiments involving cleared patches of sediment. Only by manipulation of this sort will we be able to arrive at estimates of community regeneration time. We would expand this research by varying the size of the original cleared area (from 1 $m^2$) and by establishing the patches in localities which may experience various current regimes.

5. A land-based study in an area used by whales (e.g. S.E. Cape St. Lawrence Island) may be necessary to assess feeding behavior. 'A fairly complete picture of foraging patterns (% of area used, length of dives) could be assembled from a nearshore area where whales forage. In addition a land-based camp would facilitate the recolonization experiments and the acquisition of stomach contents from stranded and harvested whales.

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